STUDIES ON THE LIFE HISTORY AND ECOLOGY OF *NOTROPIS CHALYBAEUS* (COPE)

Nelson Marshall[1]
Virginia Fisheries Laboratory

Many interesting life history and ecology studies, emanating from academic interest and an appreciation of the economic importance of forage fish, have been undertaken on minnows in the more northern states. This paper represents an attempt to extend such study not only to a new species, *Notropis chalybaeus* (Cope), but also to the ecological conditions prevalent in Florida.

Additional collecting and taxonomic study had already increased and will continue to add to the total of nine cyprinids mentioned in the key for Florida freshwater fishes by Carr (1936) but this comparatively small number is indicative of the limited representation of this family in the state. The scarcity is attributed to the relatively recent date of peninsular emergence which probably occurred during the Pleistocene according to Carr (1940). In contrast the extensiveness of the cyprinodont fauna of brackish-water derivation is largely attributed to the inter-accessibility of freshwater and marine habitats characteristic of the low peninsular topography. It is often said that the top-minnow group plays the role usually assumed by minnows in states to the north and, when not considered too critically, this statement is quite expressive of the faunal picture.

The minnow on which this study is based was described by Cope as *Hybopsis chalybaeus* in 1867, and the Schuylkill River in Pennsylvania was designated as the type locality. For many years its known distribution included only the coastwise streams and swamps from the vicinity of the Delaware River southward into peninsular Florida but recent unpublished records given to me by Dr. Carl L. Hubbs, of the Scripps Institution of Oceanography, indicate a more extensive distribution through the central United States.

Habitat Ecology

My concept of the habitat of *N. chalybaeus* is based largely on a study of this species in four creeks near Gainesville, Alachua County, Florida.

[1] Contribution from the Department of Biology, University of Florida, Gainesville, Florida.

In addition miscellaneous field work elsewhere, data obtained from publications, and discussions with other workers have supplemented my understanding of its ecology.

The habitat most intensively studied is an unpolluted stretch of Hogtown Creek on and near the property owned at that time, 1939-1941, by Roscoe McLane, Sr. (Fig. 1 and Plate II). The watershed of Hogtown Creek consists of flat terrain most of which is commonly described as pine flatwoods. All tributaries, as well as the main creek, meander and eventually drain into the underground water system through Hogtown Sink.

The other three creeks drain into Newnans Lake, east of Gainesville. Newnans Lake, in turn, drains by way of Prairie Creek and a drainage canal into Orange Lake and ultimately into the Atlantic Ocean. Prior to the construction of the drainage canal, however, Prairie Creek drained into the underground system at Alachua Sink. The three principal localities studied along these creeks are, in the order of the extent to which they were used: (1) a stretch of Little Hatchet Creek lying just north of the Gainesville-Waldo Road (Fig. 1 and Plate I), (2) Hatchet Creek where it crosses the Gainesville-Orange Heights Road (Fig. 1 and Plate I), and (3) the east tributary of Colson Branch at the road last mentioned (Fig. 1).

The creek banks at these four localities are typically low and bordered with tall trees which in many places form a shady cover effective the year around. There are extensive sand bottom areas and no rocks are exposed, except along Hogtown Creek near the McLane residence where the sandy phosphatic limestone of the Hawthorne formation forms part of the creek bed. There is usually an alternation of pools and riffles, and it is in the former that aggregations of *N. chalybaeus* are most commonly found.

After heavy rains the water level of these streams rises rapidly and the current, which is typically slow, increases. These conditions may be sustained for long periods during the rainy weather which prevails during the late spring and summer.

The water of the streams has a reddish-brown hue due to a high content of organic matter which gives an acid reaction. Like the water level and current, the acidity fluctuates with the amount of rainfall. In Hogtown Creek, the closest to neutral of the localities studied, it is common to find a pH slightly above 7.0 (colorimetric method) during the prolonged fall and winter dry periods.

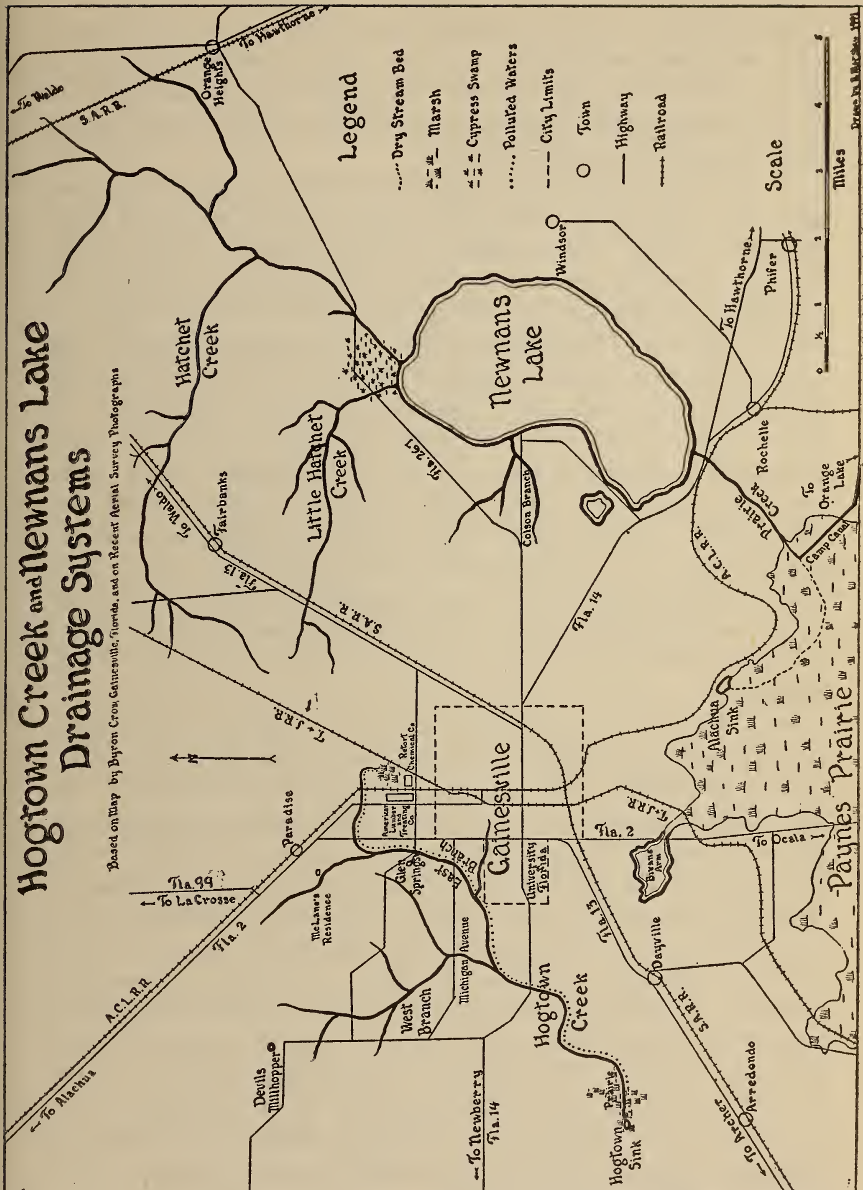
Temperature records taken at Hogtown and Little Hatchet Creek

Plate I

Upper—Little Hatchet Creek just north of the Gainesville-Waldo Road.
Lower—Hatchet Creek just south of the Gainesville-Orange Heights Road.

Plate II

A tributary of the East Branch of Hogtown Creek near the McLane residence.



Hogtown Creek and Newnans Lake Drainage Systems
Based on Map by Byron Crow, Gainesville, Florida, and on Recent Aerial Survey Photographs
Legend
Dry Stream Bed
Marsh
Cypress Swamp
Polluted Waters
City Limits
Town
Highway
Railroad
Scale
Miles
Newnans Lake
Hatchet Creek
Little Hatchet Creek
Colson Branch
Prairie Creek
Camp Canal
To Orange Lake
Alachua Sink
Paynes Prairie
Bivans Arm
Gainesville
University Florida
East Branch
Glen Springs
American Lumber and Treating Co.
Retort Chemical Co.
Michigan Avenue
West Branch
Hogtown Creek
Hogtown Sink
Prairie
Devils Millhopper
McLane's Residence
Paradise
Fairbanks
Orange Heights
Windsor
Rochelle
Phifer
Dayville
Arredondo
S.A.R.R.
A.C.L.R.R.
T.+J.R.R.
Fla. 2
Fla. 13
Fla. 14
Fla. 99
Fla. 26T
To Waldo
To Hawthorne
To Alachua
To La Crosse
To Newberry
To Archer
To Ocala

Figure 1

(Fig. 2) indicate a close correlation between the average air temperature and water temperature, the latter usually being a few degrees lower. From consecutive temperature readings through the night, it is known that the water temperature may fluctuate rapidly in correlation with changes in air temperature.

In these four localities the only cyprinid other than *N. chalybaeus* was the golden shiner, *Notemigonus crysoleucas bosci* (Cuvier and Valenciennes), a larger more vagrant minnow common to all stations. Though almost always at least second in abundance, *N. chalybaeus* was sometimes outnumbered by the mosquito fish, *Gambusia affinis holbrookii* (Girard). The bulldog pickerel, *Esox americanus* Gmelin, twice noted on dissection as having eaten *N. chalybaeus*, was the only notably piscivorous fish common to all four localities but, in addition, the Florida spotted gar, *Lepisosteus platyrhincus* De Kay, and the large-mouthed bass, *Huro salmoides* (Lacepede), were present in the largest and most populated station, that at Hatchet Creek. The eggs and young of *N. chalybaeus* are probably subject to predation by almost any carnivorous fish, including the adults of their own species. Also, in considering predation, one must mention such birds as the kingfishers and herons that feed along these streams, although surface fish such as poeciliids and cyprinodontids seem to be the chief take of these predators.

In addition to the above habitat descriptions, the following observations of two contrasting environments give some indication of the varying conditions under which *N. chalybaeus* may be found. It has been taken from small but deep stagnant pools under bridges along the Gainesville-Orange Heights Road where it crosses the cypress swamp between Little Hatchet and Hatchet Creeks (Fig. 1). In contrast *N. chalybaeus* has also been taken from the edge of the Ocklawaha River in close association with three other minnows: *Erimystax harperi* (Fowler), *Notropis hypselopterus* (Gunther), and *Notropis xaenocephalus* (Jordan). The Ocklawaha at the point where these fish were collected is about thirty yards wide, ten or twelve feet deep, and there is a strong midstream current. The minnows were congregated at the edge, however, where the flow is relatively slow. The water level was low at the time, but, when higher, the water over the edges of the bordering cypress swamps would afford many quiter situations similar to those which *N. chalybaeus* seems to prefer.

Fowler (1906) described, as follows, the habitat of a population he referred to as *N. chalybaeus abbotti* (Fowler): "This beautiful little fish,

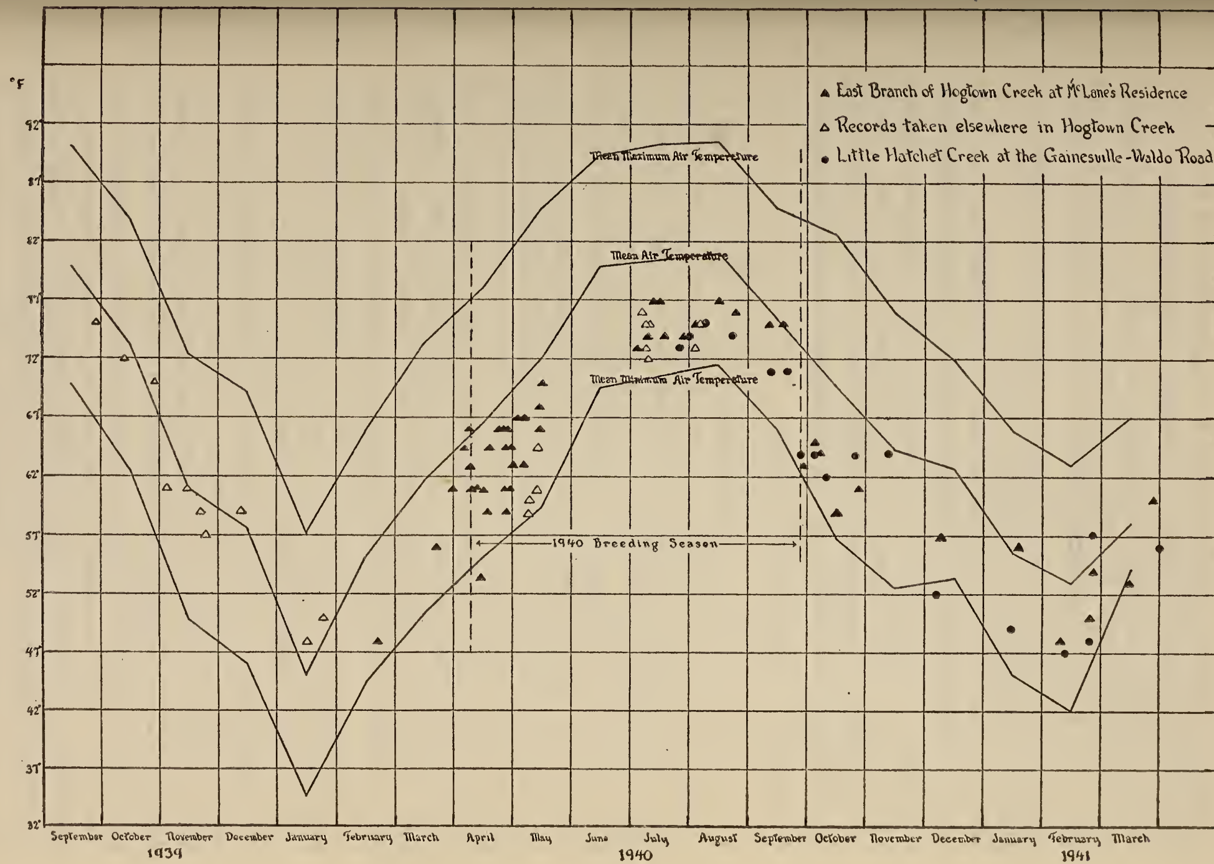


Figure 2.

A comparison of stream temperatures with the air temperature recorded at the Gainesville Station of the U. S. Weather Bureau.

in company with *Mesogonistius chaetodon*, was found to be exceedingly abundant in the little channels and runs in sphagnum banks."

Greely (1937) noted that *N. chalybaeus* is abundant in the sluggish and weedy portions of the Hackensack River in New York. Also Edward C. Raney of Cornell University, who is familiar with this species in the Middle Atlantic States, has told me that he regards this minnow as an inhabitant of sluggish streams.

The accumulated information, particularly the more detailed observations made in Florida, indicates a diversity of stream habitats for populations of *N. chalybaeus*. Although its occurrence in shallow waters and in swift currents is well established, *N. chalybaeus* should be considered an inhabitant of sluggish streams where small, quiet pools constitute its habitat and are important in its breeding (as will be discussed in the section on breeding).

Feeding

Examinations of the digestive tract contents of *N. chalybaeus* show only a few, fragmentary remnants of animal forms. There is, however, an abundance of algae and plant fragments but there is no indication that these have been digested, since those at the anal end are in the same condition as those at the anterior end of the intestinal tract. Nor is there any evidence that the digestive apparatus is adopted for the digestion of plant material. The intestine is short and has only two bends, each of 180°; the peritoneum has a light background color; the pharyngeal teeth are long and hooked, having a 1, 4-4, 1 arrangement; the mouth is large and terminal; and the eyes are large. According to widely accepted generalizations such structures are characteristic of carnivorous, not herbivorous, minnows (Forbes and Richardson, 1920, Breder and Crawford, 1922, and Hubbs and Cooper, 1936).

To interpret these seemingly inconsistent facts, feeding experiments were undertaken on 17 *N. chalybaeus* and 38 *Erimystax harperi*, another stream minnow common in Florida in which a similar discrepancy between digestive tract contents and apparent food habits was found. After a period of eight days without food and in tanks darkened to prevent the growth of algae, these fish were fed a variety of microcrustacea. They ate these voraciously after which they were immediately perserved by diverse and effective methods including slitting the belly and placing in 10% formalin. On dissection it was observed that they had torn the crustaceans into shreds and fragments, apparently through the use of their long, hooked pharyngeal teeth. Also, they were found to have plant tissues lodged in their digestive tracts in conspicuous amounts but showing no evidence of digestion, being in similar condition in the anterior and posterior ends of the tract. Since sample specimens dissected before feeding had empty digestive tracts, the only probable source of this plant material, chiefly detritus, was from within the tracts of the crustacea eaten. Thus it seems evident that in nature *N. chalybaeus* and *E. harperi* do eat animal forms in considerable quantities and that they quickly macerate and digest these, leaving in the digestive tract a misleading mass of the more resistant plant tissues from within animals eaten. This, of course, does not eliminate the possibility that plant forms are ingested to some extent under natural conditions, but, from the standpoint of nutrition, these are apparently inconsequential because they do not seem to be digested in the short alimentary tract.

The above findings can be correlated with the fact that minnows do not have stomachs, so we are actually dealing with intestinal contents. Histological studies, reviewed by Kraatz (1924), show that the digestive tract from the post-esophageal region to the anus has the gross and microscopic anatomy of a true intestine with the hepatic duct opening just posterior to the esophagus. It is well known that larger food particles must be thoroughly macerated if they are to be efficiently digested within an intestine. In cyprinids such maceration is apparently accomplished, with varying success, by the well developed pharyngeal teeth. As a consequence, material that is still in recognizable form within the intestine is not necessarily representative of the diet of the species being studied. Many food studies on minnows have been carried out without consideration of this fact. This source of error should not be ignored in the future.

That *N. chalybaeus* feeds by sight has been learned through observations on the species in aquaria and in natural habitats.These observations also indicate that it feeds on a variety of aquatic insects or insect fragments plus any other animal material small enough to be ingested. Throughout the daylight hours these minnows may be seen approaching various particles that drift by in the current or, in the case of sluggish pools, they may be seen ranging about in quest of food.Not all particles approached are taken into the mouth and, of those that are, not all are acceptable for many are soon ejected. Night observations, subject to error due to the necessity of using a flashlight, indicate that this feeding ceases wholly or partially during the night.

Breeding

In this study of *N. chalybaeus* it soon became evident that to collect sufficient specimens to determine the breeding season by examining the gonads would quickly deplete the available local populations. For this reason few large collections were made and another method was used based on external breeding characteristics of the living minnows.

Females in breeding condition can be stripped of eggs by the application of slight, though often fatal, pressure to the abdomen. Eggs thus secured, also the eggs of the most gravid of the preserved specimens examined, are yellow, opaque, and approximately 0.9 mm in diameter. In contrast to nongravid specimens, females laden with eggs of this description exhibit a distinctive robust contour in the abdominal region, a breeding character that can be discerned on living *N. chalybaeus* without injury to the fish.

Using the stripping method mentioned above and with the same high mortality resulting, milt can be stripped from the males in breeding condition. Such "ripe" males have sharp nuptial tubercles on the chin, a varying degree of tuberculation on the anterior end of the snout, and small patches of tubercles arranged in bands on the rays of the pectoral fins. A slight growth of similar tubercles is sometimes seen on the larger, probably older, females. Year around examinations of living *N. chalybaeus* from natural habitats and an examination of preserved specimens show that minnows that are not in breeding condition have little if any tubercle development, although tubercle scars are quite common.

The nuptial coloration of the male provides another useful external character. In streams in which the water has a marked reddish-brown hue this coloration is orange, the breeding color generally attributed to *N. chalybaeus*. In clearer water the breeding males develop a rosy coloration, which has lead to certain misidentifications in the past. The individual chromatophores associated with breeding are orange in all cases and when these show to their maximum extent the orange nuptial coloration results. When these orange chromatophores are less prominent, the less intense rose-colored nuptial dress results. That these changes in gross appearance are correlated with changes in the color of the water is indicated by the following observations. In 1940, when the water in Hogtown Creek was relatively clear for prolonged periods during the breeding season, the adult males developed the rosy coloration. During the spring of the next year these waters were consistently more reddish-brown from a higher organic content and the males showed an orange breeding dress. The same changes occurred in the east tributary of Colson Branch but in the reverse sequence with the clearer water and rosy coloration of the male *N. chalybaeus* population in 1940 and the dark water and orange males in 1941.

The nuptial color, whether orange or rosy, follows a rather uniform pattern in the breeding males. A faint background shade of the nuptial color is noticeable over the entire body, even on the blackish dorsal and dorsolateral surfaces and the dark pectoral fins. The breeding color is intense and striking on the dorsal fin, the caudal fin, and caudal peduncle, especially on the ventral surface of the latter. Although present, coloration is not intense on the ventral and anal fins, nor on the ventral surface of the silvery belly. Such coloration is not altogether lacking in the females or in the males out of the breeding season; however, in contrast to the striking colors of breeding males, the detection of this color necessitates close scrutiny, being most easily seen on the caudal and dorsal fins.

In summarizing the above descriptions we can list three useful external breeding characters: (1) the robust form of gravid females, (2) the tubercles of the breeding males, and (3) the nuptial coloration of the males. Occasionally, slight pressure accidentally exerted in handling the minnows, will partially expose one or more eggs at the vent of gravid females and thus additional verification of the breeding condition is obtained without the mortality that results from actual stripping.

In 1940, indications of spawning activity were witnessed on April 3. It was observed that breeding characters were maintained from that date until the end of September. The latest records indicative of breeding include a female taken on September 28 which, when subjected to slight pressure applied to the abdomen, showed eggs of mature size at the vent. Toward the end of September, all breeding characteristics disappeared and were lacking until the end of March 1941. These records indicate an extensive breeding season of approximately five and a half months extending from early or mid-April until late September. It is probable that *N. chalybaeus* has a shorter breeding period in the more northern parts of its range.

The limits of the 1940 breeding season are indicated on Fig. 5. The mean air temperature early in April, when gravid fish first appeared, approximated 66°F. The warmest month was August, with a mean air temperature 81°F., but by the close of September, when breeding was discontinued, the mean air temperature had dropped to about

73°F. As previously stated and shown by the graph, the stream temperture ran a little below these mean air temperatures.

Populations of N. *chalybaeus* tend to shift from place to place throughout the year, adjusting themselves to such factors as changes in water level and alterations of the bottom contours, but there is no distinguishable shifting of populations associated with spawning. The composition of the schools occupying any given sand bottom pool or similar situation is not altered with the onset of the breeding season. A typical area is occupied by numerous individuals of many sizes, with both sexes represented in about equal numbers. Although considerable overlap in size of adult males and females occurs, the female is generally somewhat the larger of the two.

No preparation such as nest building or clearing the bottom is made by the breeding minnows. Throughout the daylight hours of the breeding season the males chase the females about the area. On watching the males I have noticed that an individual will chase first one female and then another, apparently selecting any ripe female that ventures nearby as the objective of his pursuit. Such sexual chasing is discontinued at night but I have seen it taking place day after day during the long breeding season. From such activity one might think that spawning is a common occurrence but it is limited to the advent of optimum environment and physiological conditions. Whereas sexual chasing may be observed during times of high water and rapid currents, the culmination of courtship behavior has been observed only when there was little current in the populated areas. Just prior to spawning the sexual chasing described becomes more intense. Eventually the females discontinue their retreat from pursuing males and the actual union of individuals soon follows. Of this I could at first see nothing more than a streak of silver through the shady waters of the pool; however, after continued observations it was realized that in this act a male and female swim side by side with their silvery, ventral surfaces pressed close together and their dorsal surfaces apart. In such close proximity they dash quickly across the pool and then separate. Though, as explained below, eggs of N. *chalybaeus* have never been secured from the spawning areas, there is little doubt that this is the spawning act. Such a spawning behavior tends to distribute the eggs in a broadcast manner about the pools. Observations on fertilized eggs obtained by stripping indicate that the eggs sink and must soon adhere to the sand grains and similar particles of the stream bottom.

Normal feeding activities are not discontinued at any time during the breeding season. I have seen fish exhibiting spawning behavior refrain from sexual activities long enough to grasp at edible particles that pass by in the current. While engaged in mating activities the reactions of *N. chalybaeus* toward other species remain unchanged. The chub-sucker, *Erimyzon s. sucetta*, the golden shiner, *Notimegonus crysoleucas bosci*, and the black-spotted sunfish, *Lepomis p. punctatus*, have been observed swimming in and out of these spawning areas without arousing any marked reaction in the sexually active minnows.

The random dispersal of the eggs, the prolonged nature of the breeding season yielding few clues as to exactly when to look for eggs, and the depth and darkness of the water in the spawning pools have thwarted my attempts to obtain eggs from the stream bottom. Nevertheless, many larvae closely resembling the larvae of *N. chalybaeus* that were raised in aquaria, as discussed below, have been collected from the surface in or near the spawning areas. A variety of makeshift devices was designed in an effort to collect naturally spawned eggs but the minnows moved elsewhere to avoid the artificial additions to their surroundings. These attempts did, however, demonstrate a very loose affiliation between the minnows and their spawning areas for sexual activity was immediately resumed following such movements into new surroundings.

Observing ripe fish placed in laboratory aquaria was informative although sexual activity never went beyond the chasing stage. In the laboratory cessation of sexual activity in the dark was easily verified and it was observed that such activity was quickly resumed under the influence of artificial light.

In concluding this discussion it should be pointed out, as Hubbs and Walker (1942) did for *Notropis longirostrus*, that the breeding behavior of *N. chalybaeus* parallels in many ways that observed for other ostariophysine fishes.

Development of Eggs and Larvae

Of the methods employed in attempting to obtain fertilized eggs, one technique, that of stripping ripe males and females, was successful in a single instance on May 5, 1940. This same general procedure, which typically resulted in the death of the fish used, was repeated throughout the breeding season with minor variations in an effort to improve the technique, but without success. The work was hindered by the great length of the breeding season and the probability that the optimum physiological or actual spawning conditions are attained at intervals that are easily missed.

The single set of fertilized eggs was kept in the laboratory where they developed and the young fish were reared for a period of ten weeks through the embryonic, larval, and into the juvenile stages.

There were about fifty eggs, which represented practically all that had been obtained in stripping the female mentioned above. These eggs were not measured before development started but they closely resembled relatively large eggs 0.8 to 0.9 mm in diameter obtained by stripping other gravid females. The fertilized eggs were not adhesive at first, but the capsule soon became adherent and thus the eggs stuck to the bottom of the watch glasses in which they were kept. The original yellow color of the freshly stripped eggs lasted only a short time, then the eggs assumed a pale cream coloration.

A few minutes after fertilization the blastodisc contracted and formed a white dome above the yolk. The four-cell stage appeared about one and a half hours after fertilization. Two and a half hours later the blastoderm was composed of a mass of relatively small but easily distinguished cells. After seven hours the blastoderm had the appearance of a gray cap of minute cells on top of a more lightly colored yolk.

The field laboratory in which the eggs were kept was a small, comparatively open building with such a good circulation of air that it is probable that the water containing the eggs was comparable to the air in temperature. During the period of this embryonic development the lowest temperature recorded in the Gainesville region was 46°F., the highest 77°F., and the mean approximated 62°F. Under these conditions the eggs hatched in from about 52 to about 56 hours, the majority hatching about 54 hours after fertilization. Eggs of goldfish, *Carassius auratus*, observed by Battle (1940) hatched in from 64 to 72 hours at temperatures varying between 75° and 82°F. Other records of the hatching time of cyprinids are available and Battle has reviewed some of these, thereby demonstrating an inverse relation between the time of hatching and the temperature involved.

Just prior to hatching the embryos were active within the egg. They freed themselves by lashing movements of the tail which eventually ruptured the egg capsules.

Measurements used in describing the larval and juvenile fish as they developed from these eggs were taken as follows:

Total length: Tip of the snout to tip of the caudal fin.

Standard length: Tip of the snout to the posterior end of the notochord on the earliest stages and to the posterior end of the vertebral column on older stages.

Length to vent: Tip of the snout to the vent.

Length of head: Prior to the development of the operculum it was necessary to estimate the posterior border of the cephalic region and make measurements on that basis. Starting with fish having a standard length of 5.4 mm it was possible to measure from the tip of the snout to the posterior border of the operculum. The soft, fleshy extension of the operculum was not included.

Width of head: Included the protruding eyes. This was not a very satisfactory measurement but the best that could be devised to work effectively on very early stages.

Greatest diameter of eye: The greatest diameter was from the anterior to the posterior borders which represented the longest axis of the slightly elliptical eye.

Greatest depth before vent: Included the yolk sac before it was absorbed but did not include the fins.

Measurements were always taken along a straight line and on the normally curved early stages maximum straight line dimensions taken without straightening the specimens have been used.

The measurements are recorded in Table 1 and the rate of growth is presented graphically in Fig. 5. In addition, the following notes on the gross appearance and activity of certain stages are given. In referring to these stages the terminology recommended by Hubbs (1943) has been used.

Prolarva—Newly-hatched (Fig. 3): Total length 2.3 mm, standard length 2.25 mm.

At this stage the larva is curved downward at the anterior and posterior ends so that its dorsal outline is arcuate. The eye is barely noticeable. The myomeres are very indistinct but counts indicate that few if any are added as the larva grows. There is a single, non-rayed caudal fin that is continuous along the dorsal and ventral body surfaces in the posterior region, thus adding considerable expanse to the tail region. The swimming activities at this stage are greatly encumbered by the large size of the yolk. Propulsion is effected by the tail and the resulting movement is random to an extreme.

Prolarva—Age 1 day (21 hours) (Fig. 3): Total length 3.2 mm, standard length 3.1 mm.

There is a distinct reduction in the size of the yolk sac. The anterior region of the body is still curved downward but the posterior region has straightened. The swimming activity consists of vig-

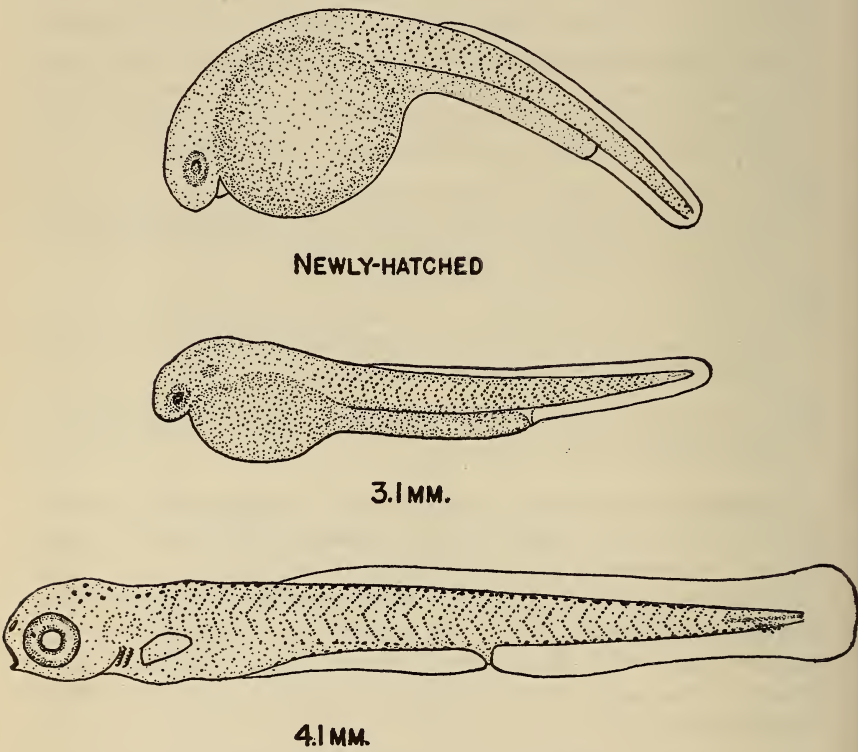


Figure 3.—Early stages of *Notropis chalybaeus*
Standard length 2.25 mm., Newly-hatched
Standard length 3.1 mm., Age 1 day
Standard length 4.1 mm., Age 5 days

orous, somewhat random movements which eventually carry the larva to the water surface where the tail movements discontinue and it sinks. Soon after it reaches the bottom the whole process is repeated. A very similar behavior is described for *Notropis girardi* by Moore (1944) who discusses it as an adaptation keeping these early stages free from the shifting sands and silt of their stream habitat.

Prolarva—Age 2 days: Total length 3.5 mm, standard length 3.3 mm.

There is a continued reduction in the size of the yolk sac. The curvature of the anterior region is lessened.

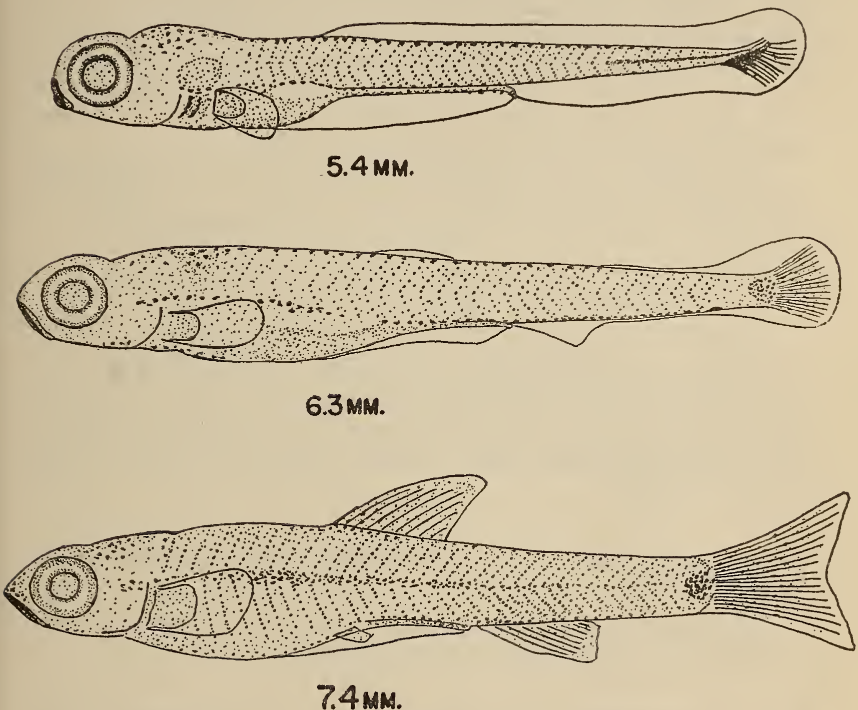


Figure 4.—Early stages of *Notropis chalybaeus*
Standard length 5.4 mm., Age 19 days
Standard length 6.3 mm., Age 33 days
Standard length 7.4 mm., Age 47 days

Prolarva—Age 3 days: Total length 3.9 mm, standard length 3.7 mm.

The yolk sac has been reduced in size and has become more cylindrical in shape. Pigmentation is evident for the first time; melanophores being located in the mid-dorsal and posterior ventral regions. A few in the latter position are anterior to the vent but most are posterior. There is also a slight sign of pigmentation in the eye. The buds of the pectoral fins are in evidence.

It was noted that swimming ability steadily improved with the growth of the embryo and decrease in size of the yolk sac.

Postlarva—Age 5 days (Fig. 3): Total length 4.3 mm, standard length 4.1 mm.

The downward curvature of the anterior region no longer exists. Melanophores occur along almost the entire dorsal and ventral surfaces of the body, exclusive of the fins, but no pigmentation occurs between these two regions of melanophore development. The mouth is now functional. The presence of the swim bladder can be noticed through the dorsal surface of the translucent body. The larva by this time is able to maintain an upright position while swimming and usually assumes such a position when at rest.

The aquaria in which the larvae were reared were stocked with microscopic organisms, chiefly from hay infusions. This apparently served as a very adequate food supply for the developing fish.

Postlarva—Age 9 days: Total length 4.6 mm, standard length 4.3 mm.

The pectorals show increased development but there are no other evidences of fin development. The body is more elongate. The swimming ability has greatly increased. The swimming movements and positions assumed when resting at this stage give the fish the appearance of being hinged in the region of the swim bladder. This peculiar hinge-like effect has also been seen in larvae taken from the stream.

Postlarva—Age 19 days (Fig. 4): Total length 5.7 mm, standard length 5.4 mm.

The notochord shows an upward curvature at the caudal end and the first rays of the caudal fin are in evidence.

Postlarva—Age 26 days: Total length 6.2 mm, standard length 5.7 mm.

The posterior end of the notochord is concealed beneath a concentration of melanophores in the form of a caudal spot. Caudal fin rays have increased in number. The caudal and the pectorals are the only fins in evidence except for the non-rayed larval fin.

Postlarva—Age 33 days (Fig. 4): Total length 7.0 mm, standard length 6.3 mm.

The non-rayed caudal fin of the larva has almost vanished. The outline of the future anal fin is clearly evident. Very early signs of the dorsal fin can be seen and portions of the reduced larval fin remain where the ventrals and anal later develop. The mouth begins to resemble that of the adult. This may be regarded as representing an early stage in the gradual transition from postlarva to juvenile fish.

Juvenile—Age 47 days (Fig. 4): Total length 9.2 mm, standard length 7.4 mm.

The caudal fin has become bifurcate. Both the dorsal and anal fins have differentiated and the buds of the ventral fins have appeared. Additional pigmentation is present in the form of a line of melanophores from the head to the caudal spot on each mid-lateral surface. The fish is beginning to resemble the adult in both appearance and locomotion.

Juvenile—Age 69 days: Total length 14.8 mm, standard length 11.6 mm.

The fin development is complete or nearly so. The pigmentation is the same as on the 7.4 mm specimen. In gross external appearance it resembles the adult except for size, its lack of scales, and the lack of adult pigmentation.

Table 1, in addition to listing the measurements taken on the fish reared from the available fertilized eggs, offers, for comparison, percentage evaluations of the various dimensions as derived from measurements of ten *N. chalybaeus* between 20 and 30 mm standard length, ten between 30 and 40 mm, and ten between 40 and 50 mm. Except for the 20 to 30 mm group in which four specimens from Hatchet Creek collections were used, all of them had been collected from Hogtown Creek where the fish yielding the fertilized set had been taken. To avoid misleading comparisons, the greatest depth before the vent was not taken on gravid fish. A notation on the table indicates that the measurements of the head width for these larger specimens did not include the eyes, the protrusion of which varied too greatly.

The age of these larger *N. chalybaeus* has not been determined. The lengthy breeding season prevents the determination of age by length groups; moreover, the scales reveal nothing that I have been able to correlate with age, such as was done in my study (1939) on the annulus of *Notropis cornutus crysocephalus* (Rafinesque). This difficulty encountered in interpreting scales may be at least partially attributed to the small size of the scales and the lack of seasonal changes comparable to those existing in regions where the formation of annuli is known in related forms.

The initial rate of growth following hatching is quite rapid (see Table 1 and Fig. 5) even when one makes allowance for the rapid increase in antero-posterior dimensions that occurs when the larva straightens out shortly after hatching. When the yolk sac has been

TABLE I

Measurements of a series of immature *Notropis chalybaeus* reared from fertilized eggs, with appended data on thirty larger fish of unknown ages

Age in Days	Number of Specimens	Standard Length	Total Length		Length to Vent		Length of Head		Width of Head		Greatest Diameter of Eye		Greatest Depth Anterior to Vent	
			mm.	% of s.l.	mm.	% of s.l.	mm.	% of s.l.	mm.	% of s.l.	mm.	% of s.l.	mm.	% of s.l.
0	2	2.25	2.3	102	1.83	81	0.44	20	0.44	20	0.16	7	0.80	36
1	1	3.1	3.2	103	2.2	71	0.60	19	0.44	14	0.16	5	0.67	22
2	1	3.3	3.5	106	2.2	67	0.55	17	0.44	13	0.22	7	0.60	18
3	1	3.7	3.9	105	2.3	62	0.60	16	0.50	14	0.28	8	0.56	15
4	1	4.0	4.2	105	2.6	65	0.67	17	0.58	15	0.22	6	0.50	13
5	2	4.15	4.35	105	2.7	65	0.68	16	0.60	14	0.285	7	0.55	13
6	1	4.2	4.4	105	2.7	64	0.68	16	0.64	15	0.30	7	0.55	13
7	1	4.2	4.4	105	2.6	62	0.68	16	0.65	15	0.33	8	0.55	13
8	1	4.2	4.4	105	2.7	64	0.68	16	0.64	15	0.31	7	0.55	13
9	1	4.3	4.6	107	2.6	60	0.77	18	0.66	15	0.33	8	0.55	10
19	1	5.4	5.7	106	3.5	65	1.0	19	0.90	17	0.44	8	0.70	13
26	1	5.7	6.2	109	3.7	65	1.2	21	1.10	19	0.50	9	0.77	14
33	1	6.3	7.0	111	4.2	67	1.3	21	1.1	17	0.54	9	0.90	14
39	1	5.7	6.3	110	3.7	65	1.0	18	1.2	21	0.60	11	0.88	15
47	1	7.4	9.2	124	5.0	68	1.8	24	1.5	20	0.77	10	1.50	20
54	1	7.2	8.7	121	4.9	68	1.8	25	1.4	19	0.78	11	1.29	18
61	1	10.5	13.0	124	6.9	66	2.7	26	1.8	17	1.10	10	2.20	21
69	1	11.6	14.8	128	7.3	63	2.8	24	2.2	19	1.3	11	2.20	19
?	10	20–30		132±1.8		64±1.7		25±1.0		13±0.8*		9±0.9		20±1.9
?	10	30–40		133±2.3		66±1.4		25±1.0		13±0.6*		9±0.7		22±0.9
?	10	40–50		132±1.9		66±1.4		25±0.6		13±0.6*		9±0.7		22±1.0

*The width of the head measurements on which these percentages were based was taken across the skull and did not include the protruding eyes as did the head measurements on smaller fish.

consumed and the larvae resort to feeding by mouth the rate of growth tapers off, a fact definitely demonstrated under aquarium conditions and probably at least partially true in nature. No other shifts in rate of growth marked enough to be considered valid from these few specimens and under these artificial rearing conditions, have been detected.

Gregariousness and Movements

The larvae of *N. chalybaeus* swim in aggregations composed of a varying number of individuals, completely independent of and unattended by adults. Although a single aggregation may sometimes be composed of the young of one parent, it is probable, as indicated by the heterogeneous sizes within such a group, that young of several different parents and different hatching dates are intermixed.

When subjected to currents artificially produced in the laboratory, the larvae exhibit a positive rheotaxis but practically no ability to maintain a position in the current. It is probable that great losses of young result from the frequent swift current conditions common during the rainy season of June and July when many larvae are in the streams. A natural defense against losses from this cause is indicated by the common occurrence of larval forms in protected miniature embayments and harbors of various sorts.

Sometime after development has reached the juvenile stages the young *N. chalybaeus* become an integral part of the adult schools or aggregations. Such groups are seldom compact and, except when in currents, do not have an integrated formation. They are composed of fish of many sizes with both sexes represented in about equal numbers. The composition of such schools is definitely unstable. Groups sometimes split and some unite, with a considerable exchange of members. Individuals are seen moving freely from one aggregation to another. Sometimes they remain isolated or form groups composed of as few as two to five minnows.

Aggregations of *N. chalybaeus* can not be classed as schools in the most restricted sense associated with that term. They somewhat resemble the schools which Breder and Nigrelli (1935) describe for such fishes as *Lebistes* and *Fundulus* as follows: "Such a school does not primarily aim at going anywhere, the members being 'browsers', not plankton feeders, with the consequence that individuals point primarily at scattered food objects. Observe them, however, in a current, as *Fundulus* in a tideway, and they are found to present as well-integreted a school as mackeral." Likewise, when in a current, minnows like *N. chalybaeus* and many similarly behaving forms must continually move forward with respect to that current in order to maintain their position in the stream and, in so doing, they too form a rather definitely patterned school. In short, an organized school of *N. chalybaeus* is essentially a summation of the minnow's gregariousness and its positive rheotaxis.

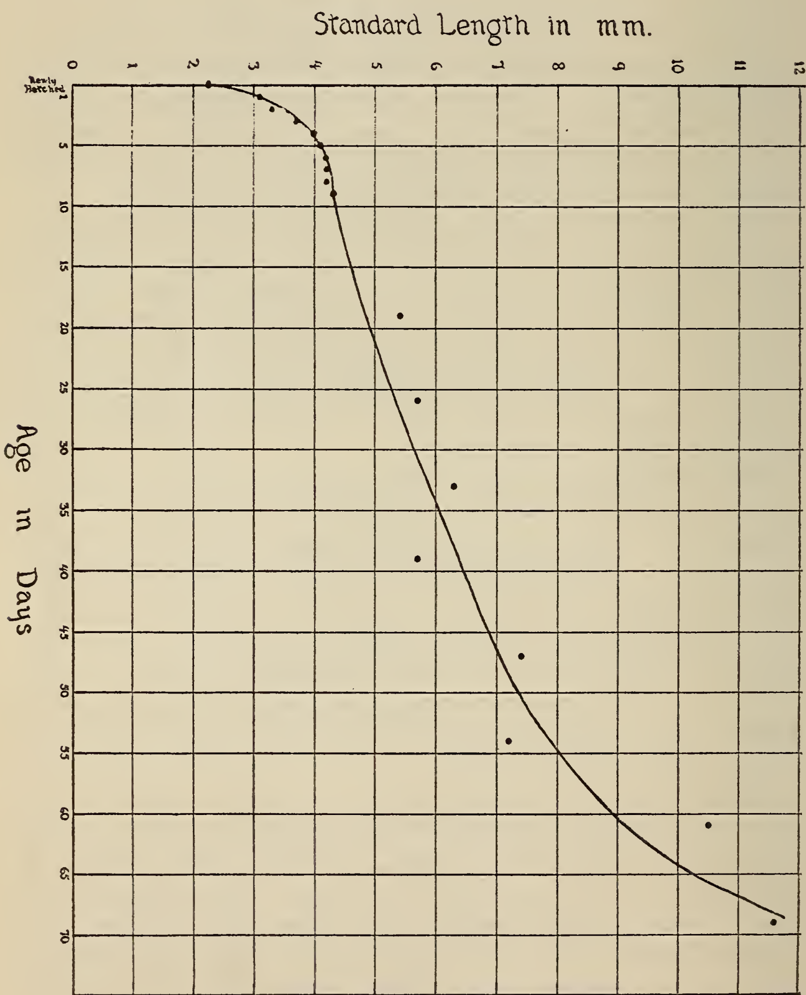


Figure 5.
Rate of growth of the early stages of *Notropis chalybaeus* reared in aquaria

The aggregations, particularly the better organized aggregations that *N. chalybaeus* forms when in currents, appear to fit the generalizations made by Parr (1927) to the effect that schooling performances are enacted on the basis of purely visible stimuli. This generalization has as a corollary the fact that there will be a dispersal in the darkness; moreover, observations carried out at night, though inevitably difficult and somewhat inaccurate due to the necessity of using a flashlight, show that this also applies to *N. chalybaeus*. On the other hand, the favorable conditions of the inhabited situations tend to keep the groups of *N. chalybaeus* together with the result that the effects of this dispersal are limited.

The breeding behavior of *N. chalybaeus* has little effect on the structure of the aggregations other than to slightly expand the groups, which are seldom very compact. When we consider, along with this continued aggregating behavior, the fact that the sexual dimorphism is not very pronounced, we see that this species fits another generalization of Parr's (1931) to the effect that the schooling habit of fishes exists in an inverse ratio to sexual dimorphism to as great an extent as other influences permit.

Aggregations containing *N. chalybaeus* in association with other species are known. I have observed and seined groups composed of the minnows, *Erimystax harperi*, *Notropis hypselopterus*, *N. chalybaeus*, and *Notropis xaenocephalus* in the Ocklawaha River and one of its tributaries. Furthermore, as best I can tell from seine hauls limited to given aggregations of fishes, the cyprinodont, *Chriopeops goodei*, though always greatly outnumbered, frequently maintains a markedly close association with aggregations of the cyprinids *E. harperi*, *N. chalybaeus*, and *N. xaenocephalus*. Such observations give strength to the following statement made by Breder and Nigrelli (1935): "It is inferred that schools of various fish mix when they are sufficiently alike in habits to make it possible."

The wanderings of *N. chalybaeus* are apparently quite restricted. Given habitat niches have been known to maintain a population for weeks at a time. When suddenly the minnows are no longer present in their usual localities, populations may be readily found in previously uninhabited but suitable places nearby. My accounts of these movements is not based on data from marked specimens but is taken from an analysis of repeated seining activities in the Hogtown Creek and Little Hatchet Creek stations.

Often the movements of *N. chalybaeus* are associated with changes in the stream contours and the water level. The minnows exhibit a general, but not an uninterrupted, tendency to move to the more quiet water when this is possible. Probably some of the less obvious factors influencing movements include the sources of available food. As stated above there are no distinctive migratory movements correlated with spawning.

Acknowledgments

There are many people to whom I am indebted for aid in connection with this study, and it is unfortunate that lengthy expressions of appreciation cannot be given here. The most active in rendering advice were Professors J. Speed Rogers, Archie F. Carr, T. H. Hubbell, and W. J. K. Harkness, all of whom were at one time associated with the Department of Biology at the University of Florida. Professor Carl L. Hubbs of the Scripps Institution of Oceanography and M. B. Trautman of the F. T. Stone Laboratory have contributed many very pertinent suggestions and facts. The cooperation of Mr. and Mrs. Roscoe McLane, Sr., and my colleague, William M. McLane, with regard to the facilities available at their residence near Gainesville was of great value. My wife, Grace Terry Marshall, has helped in the field, in the laboratory, and in preparing this paper.

Summary

This study, carried out in northern Florida, indicates the suitability of a wide diversity of stream habitats for the maintenance of populations of *Notropis chalybaeus*. The small pools, such as may be found at various places along the course of many streams, represent its habitat niche.

This cyprinid, like many others of the family, is valuable as a forage fish. It is a sight feeder and, though digestive tract analyses show a high percentage of algae and plant detritus with very few recognizable animal remains, this species has the anatomy of a decidedly carnivorous minnow. That it actually is carnivorous is demonstrated by experimental procedure. In explaining the contradictory digestive tract analyses, it is pointed out that minnows lack stomachs; therefore the digestive tract contents used are from the intestine where much of the animal material lies macerated and digested beyond recognition while comparatively indigestible plant tissues may accumulate in quantity.

Near Gainesville, Florida, the breeding season of *N. chalybaeus* extends over a period of five and a half months from early or mid-April till late September. At the time of breeding the male, which is gener-

ally slightly smaller than the female, shows a marked development of tubercles on the chin and other limited areas, also a nuptial coloration which is distributed over the entire body but is especially concentrated in certain areas toward the dorsal and posterior regions. This coloration, due in all cases to orange chromatophores, ranges from a true orange on fish living in dark, reddish-brown waters to a less intense rosy effect on fish from clearer streams.

In the streams studied, the sand bottom pools, typical habitat niches, serve as the spawning areas for the aggregations of *N. chalybaeus*, which neither migrate nor change in composition with the onset of the breeding season. No preliminary activities such as nest building occur and the first evidence of breeding behavior is a promiscuous sexual chasing in which individual adult males chase one female then another about the populated areas. This sexual chasing is carried on during daylight hours of the prolonged breeding season but spawning, the culmination of this breeding behavior, is restricted to times of low, quiet water. Just prior to the spawning act females discontinue their flight from pursuing males. Then the paired individuals are seen effecting a quick dash side by side across the spawning area with their ventral surfaces pressed close together. After this they separate and chasing is renewed.

This spawning act effects a rather disperse distribution of the eggs, which sink to the bottom of pools and adhere to sand particles and similar bottom materials. Although stripping was fatal to the adults involved, this method did in one case yield a set of fertilized eggs. These eggs hatched in about 54 hours at a mean temperature of about 62°F.

After the fish hatches the yolk sac is quickly absorbed and by the fifth day the mouth begins to function, at which time the initial rapid rate of growth tapers off. The larvae swim in large aggregations, often found in very protected parts of the stream. When they have attained a standard length of 6 mm (at the age of 30 days in aquarium-reared fish), these larvae undergo a gradual metamorphosis into the juvenile form and, when they have attained a standard length of 12 mm (70 days in aquarium-reared fish), they greatly resemble the adults in external appearance except for size, lack of adult pigmentation, and a lack of scales. These young fish become associated with the heterogeneous aggregations of larger *N. chalybaeus*.

Aggregations of this species exhibit very limited movements along the stream, many of which can be correlated with changes in the water level and in the contours of the stream bottom. The gregarious tendency, so typical of *N. chalybaeus*, is seldom interrupted except at night when the visual stimuli essential to their aggregating behavior become ineffective. Groups of this species are composed of minnows of various sizes with both sexes being represented in about equal numbers; furthermore, it is not unusual to find a school including, in addition to *N. chalybaeus*, other species with similar habits.

Literature Cited

Battle, H. I.

1940. The embryology and larval development of the goldfish (*Carassius auratus* L.) from Lake Erie. *Ohio Jour. Sci.*, 40 (2): 82-93.

Breder, C. M., Jr., and D. R. Crawford.

1922. The food of certain minnows. A study of the seasonal dietary cycle of six cyprinoids with special reference to fish culture. *Zoologica*, 2 (14): 287-327.

Breder, C. M., Jr., and R. F. Nigrelli.

1935. The influence of temperature and other factors on the winter aggregations of the sunfish, *Lepomis auritus*, with critical remarks on the social behavior of fishes. *Ecology*, 16 (1): 33-47.

Carr, A. F., Jr.

1936. A key to the fresh-water fishes of Florida. *Proc. Fla. Acad. Sci.*, 1: 72-86.

1940. A contribution to the herpetology of Florida. *Univ. of Fla. Publ., Biol. Sci. Series*, 3 (1): 1-118.

Cope, E. D.

1867. Synopsis of the cyprinidae of Pennsylvania. *Trans. Amer. Phil. Soc.*, 13: 351-399.